# ESTABLISH WATER QUALITY OBJECTIVES AND A TOTAL MAXIMUM DAILY LOAD FOR DISSOLVED OXYGEN IN SUISUN MARSH AND ADD SUISUN MARSH TO SF BAY MERCURY TMDL


## STAFF REPORT FOR PROPOSED BASIN PLAN AMENDMENT

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION
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# 1. INTRODUCTION

This Staff Report presents the supporting documentation for a Basin Plan amendment to establish site-specific water quality objectives and a Total Maximum Daily Load (TMDL) for dissolved oxygen (DO) in Suisun Marsh wetlands, specifically in sloughs and channels (Suisun Marsh). The Report also provides the reasoning for the proposal to extend the San Francisco Bay Mercury TMDL to Suisun Marsh, which is also impaired by mercury.

Section 303(d) of the federal Clean Water Act (CWA) requires that states identify water bodies - bays, rivers, streams, creeks, and coastal areas - that do not meet water quality standards and identify the pollutants that cause the impairment. The San Francisco Bay Regional Water Quality Control Board (Water Board) is responsible for identifying impaired surface waters and developing related TMDLs in the San Francisco Bay Region.

The Suisun Marsh wetlands are listed under CWA section 303(d) as impaired by low DO due to high organic carbon (OC). Additionally, the marsh is listed as impaired by mercury, nutrients, and salinity/TDS/chlorides (Table 1-1). This Staff Report only addresses water quality impairments due to low DO/organic enrichment and mercury. Salinity conditions in Suisun Marsh are to a great degree dependent on Delta water management regulations and decisions and affected by the overall hydrology of the Central Valley watershed (ranging from wet to critically dry). The State Water Board oversees the development and implementation of salinity objectives, and decisions regarding the need to modify the salinity objectives in the marsh will be ultimately made through the State Water Board's regulatory process as part of its revisions to the Bay–Delta Water Quality Control Plan.

Over the past two decades, low DO concentrations and fish kills have been observed in Peytonia, Boynton, Suisun, and Goodyear sloughs in Suisun Marsh (O'Rear and Moyle, 2010, Schroeter and Moyle, 2004). Fish kills were documented for the fall seasons of 1999, 2001, and 2003. In October 2004, a widespread fish kill was observed in Peytonia, Boynton, Goodyear, and Suisun sloughs (Schroeter and Moyle, 2004). In October 2009, 100% mortality of fishes was observed in Goodyear Slough (O'Rear and Moyle, 2010). The fish kills were linked to releases of low DO waters from managed wetlands. DO concentrations below 1-2 mg/L were measured in marsh sloughs when discharges from the managed wetlands occurred, which can result in mortality to some species of fish.

Because of the aforementioned low DO and mercury concerns, this TMDL is necessary to examine the water quality issue more closely, identify sources of pollutants, and specify actions that will result in the restoration of adequate DO levels in Suisun Marsh.

Improving DO levels in Suisun Marsh sloughs is a key component of maintaining the marsh's habitat value. Suisun Marsh encompases some 85,000 acres of tidal marsh, managed wetlands, and waterways in southern Solano County. It is the largest remaining wetland in San Francisco Bay and includes more than ten percent of California's remaining wetlands. The marsh provides critical wintering habitat for waterfowl on the Pacific Flyway and, because of its size and estuarine location, supports a diversity of plant communities. These provide habitats for a variety of fish and wildlife, including numerous ecologically important species (e.g., winter-run chinook salmon, delta smelt, Sacramento splittail, Ridgway's rail, California least tern, saltmarsh harvest mouse; SMPP 1997). Among them, the endangered salmonids are particularly sensitive to low DO.

Two-thirds, or about 52,000 acres, of the Suisun Marsh wetlands are managed wetlands, meaning they are diked and managed to provide seasonal wetland habitat for resident and migratory wildlife focused on better waterfowl food resources. Accordingly, water control actions and vegetation management at managed wetlands play an important role in maintaining adequate DO levels of discharge water.

In addition, large-scale efforts to restore tidal wetlands have been proposed in Suisun Marsh. Several regional ecosystem planning efforts call for extensive additional restoration and mitigation projects in the decades to come, including the Suisun Marsh Habitat Management, Preservation, and Restoration Plan, Bay Delta Conservation Plan, Bay-Delta Plan, and others. These planning efforts may ultimately result in the restoration of tidal action to at least 5,000 acres of managed wetlands in Suisun Marsh. While restoration may result in short-term localized and system-wide changes in DO, the precise effects of restoration projects have not been taken into account in this TMDL.

**Table 1-1**
**2010 California 303(d) list of water quality limited segments**

| Water Body Name | Water Type | Watershed Calwater/ USGS HUC | Pollutant | First Year Listed |
|---|---|---|---|---|
| Suisun Marsh wetlands | Wetland, tidal | 20723000/ 18050001 | Organic enrichment/low dissolved oxygen | 1992 |
| Suisun Marsh wetlands | Wetland, tidal | 20723000/ 18050001 | Mercury | 1992/2010 [1] |
| Suisun Marsh wetlands | Wetland, tidal | 20723000/ 18050001 | Nutrients | 1992 |
| Suisun Marsh wetlands | Wetland, tidal | 20723000/ 18050001 | Salinity/TDS/Chlorides | 1992 |

[1] In 2010 the listing was clarified to specifically identify mercury as a source of impairment

Tidal marshes and managed wetlands are naturally rich in organic carbon and low DO due to the growth of wetland plants and their subsequent decay in these environments. The natural tendency for organic enrichment in wetland environments is exacerbated in Suisun Marsh due to wetland management activities. Flooding and draining of managed wetlands to leach salts from the soils and circulate water through the hunting season and mowing/disking of vegetation can potentially increase the release of organic carbon from wetland soils and vegetation beyond what would naturally occur. The critical periods of low DO in sloughs have been determined to be in the fall months, when managed wetland owners discharge their ponded water to the sloughs.

Other sources, such as surrounding tributaries, exchange with Suisun Bay, and discharge from the Fairfield-Suisun Sewer District wastewater treatment plant, may contribute organic carbon and nutrients to sloughs and water channels in the marsh but seem to have less direct impact on water quality in the marsh (Tetra Tech 2013a). After evaluation of the available data and common nutrient enrichment indicators, we concluded that the anthropogenic nutrient loading is not a significant contributor to low DO observed in the sloughs (Parker et al. 2015).

This report follows the findings and recommendations of the Mercury TMDL for San Francisco Bay (Bay Mercury TMDL; SFBRWQCB 2006). The previously-established elements of the Bay Mercury TMDL, including source analysis, numeric targets, linkage analysis, TMDL, load and wasteload allocations, considerations of seasonal variations, and margin of safety, and implementation plan also apply to Suisun Marsh. Actions required by the Bay Mercury TMDL are already addressing the general mercury concerns in the region, including in Suisun Marsh, by such means as source reduction and pollution prevention. However, the marsh could be also a source of methylmercury. Low DO and high organic content in the marsh favor methylation. For this reason, this TMDL proposes to address the mercury impairment by ensuring that discharges from managed wetlands maintain DO at certain levels and, therefore, reduce the potential for convertion of mercury to toxic methylmercury.

This Staff Report comprises the following main components: 1) problem statement and impairment assessment; 2) numeric targets, 3) identification of sources of organic carbon, nutrients, and mercury to the sloughs; and 4) an estimate of allowable loads of organic carbon inferred from the numeric targets of DO and linkages to fish kills and water quality problems. A brief summary of the Bay Mercury TMDL requirements and the explanation of how the mercury targets established for the Bay are also relevant in Suisun Marsh is also included. Finally, Section 12 of the Staff Report describes the implementation actions that have been completed and proposed to prevent drops in DO and our plans to monitor to determine whether the TMDL targets have been achieved.

This Staff Report has undergone external scientific peer review as required under section 57004 of the Health and Safety Code focusing on proposed DO water quality objectives for Suisun Marsh and the TMDL for DO in Suisun Marsh sloughs. The scientific basis for the TMDL for mercury in Suisun Marsh is the same as the basis for the San Francisco Bay Mercury TMDL and did not undergo scientific peer review. The Basin Plan amendment includes language for the Suisun Marsh DO objectives and TMDL and shows changes to Section 7.2.2, San Francisco Bay Mercury TMDL, in the Basin Plan appending Suisun Marsh to the list of water bodies for which the Bay Mercury TMDL applies. The Basin Plan amendment also includes some minor non-regulatory amendments to language in the Basin Plan for clarification.

Appendices A, B, and C describe the data used in the assessment, the results of the water quality analysis, and the DO simulations in selected sloughs with the HEC-RAS model. A summary of the Expert Panel recommendations on derivation of the site-specific objectives for DO is in Appendix D.

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# 2. WATERSHED OVERVIEW

## 2.1. SUISUN MARSH AREA

Suisun Marsh, located within southern Solano County, is the largest contiguous brackish water marsh remaining on the west coast (Figure 2-1). It is a part of the San Francisco Bay-Sacramento/San Joaquin River Delta estuary ecosystem and encompasses an area of 116,000 acres, including 52,000 acres of managed wetlands, 27,700 acres of upland grasses, 6,300 acres of tidal wetlands, and 30,000 acres of bays and sloughs. Figure 2-1 shows the major features of Suisun Marsh.

Starting in the 1800s, nearly all of the historic tidal marshes were diked to create grazing and farm lands. The diked areas are separated from tidal sloughs by artificial levees and water exchange is controlled by gated culverts and other water control structures. When these diked agricultural lands became less productive due to upstream water diversions, large-scale water projects, and increasing salinity in the marsh soils, many of these diked lands were converted to duck clubs. The majority of the marsh is used by over 150 private duck clubs today, which maintain diked seasonal wetlands for wintering waterfowl and hunting (Figure 2-2) as well as other resident and migratory wildlife species. In addition, some publicly owned portions of the marsh, including the Grizzly Island Wildlife Area, are managed as wetlands supporting public waterfowl hunting.

In both the historic tidal marshes and currently managed ponds, waterfowl have found wintering habitat that meets their needs for water, food, and cover (DWR 2001). At present, the marsh serves as a resting and feeding ground for millions of waterfowl migrating on the Pacific Flyway and provides essential habitat for more than 221 bird species, 45 mammal species and more than 40 fish species, including endangered species. The Marsh is critical to the survival of wintering birds on the Pacific Flyway, particularly during drought conditions, and represents a unique resource for a wide range of aquatic and wildlife species. In dry years, the marsh supports more than one-quarter of central California wintering waterfowl population.

### *2.1.1 Hydrology*

Two major tidal sloughs connect Suisun Marsh with Grizzly Bay: Montezuma and Suisun Sloughs (Figure 2-1). The major tributary sloughs to Montezuma are Denverton and Nurse Sloughs. Cutoff Slough and Hunters Cut connect Suisun and Montezuma Sloughs. The major tributaries to Suisun Slough are Peytonia, Boynton, Cutoff, Wells, and Goodyear (Figure 8-1).

The hydrology of Suisun Marsh is affected by several factors, including Delta outflows, rainfall, tides, local creek inflow, and the Fairfield Suisun Sewer District (FSSD) Wastewater Treatment Plant discharge. The flooding and draining operations of the managed wetlands also have a strong effect on the hydrology in the sloughs.

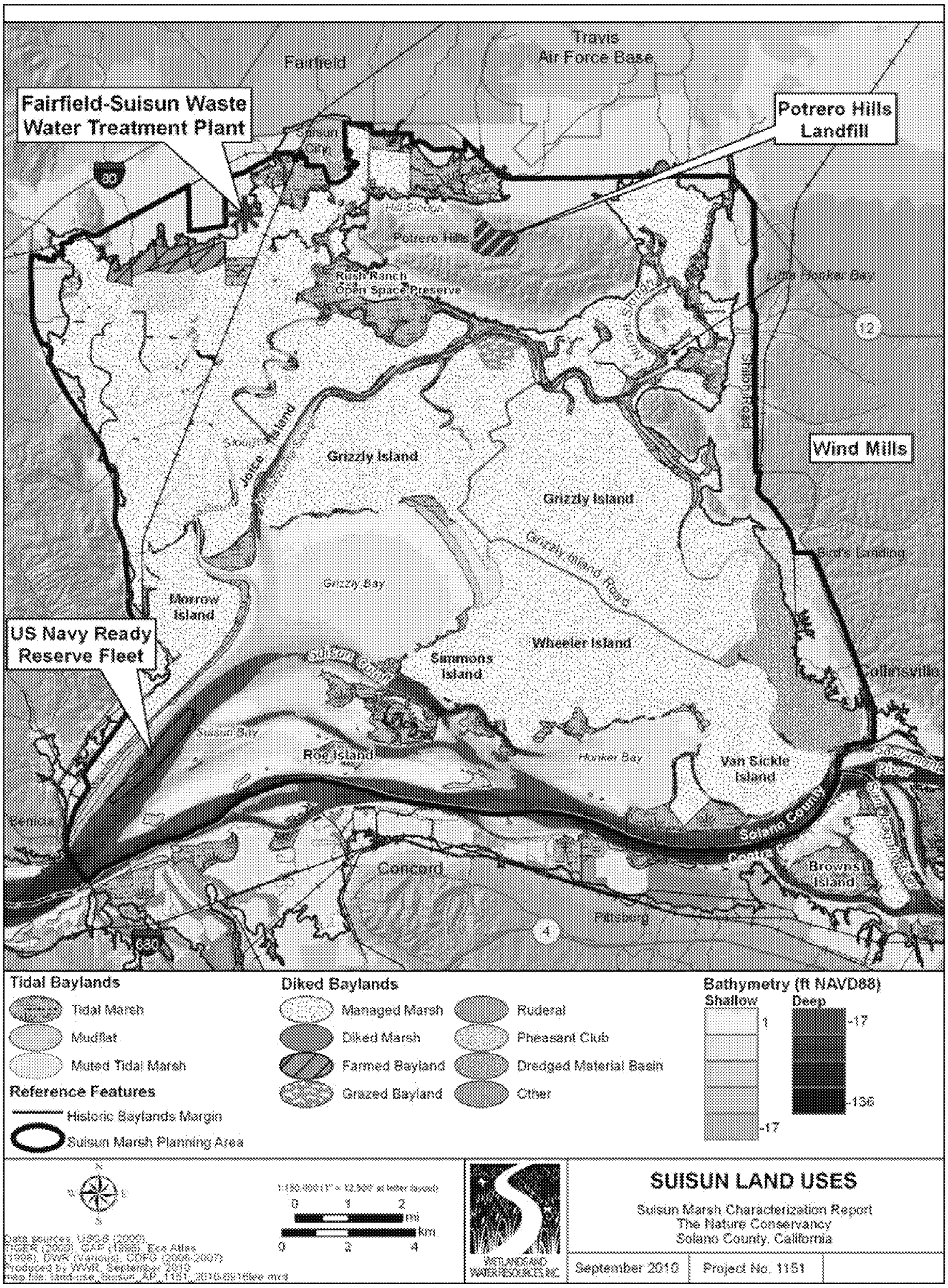



**Figure 2-1 Suisun Marsh location and land uses**


Colored areas represent the tidal wetland restoration regions assessed in SMP (2014)

**Figure 2-2 Duck club properties (numbered) in Suisun Marsh**

### Tidal Exchange

Tides are the dominant driver of flows in the sloughs of Suisun Marsh. The Marsh experiences mixed semi-diurnal tides, with two daily tides of unequal height (Siegel et al. 2011). In Boynton Slough, tidal flows ranged between -800 and +1200 cfs and in Peytonia Slough, tidal flows ranged between about -700 and + 800 cfs. The variations of tidal stage depend upon three time scales of tidal processes: daily unequal high and low tides, biweekly spring-neap tidal cycle, and quarterly seasonal tides (Schureman, 1971; cited in Siegel et al. 2011).

### Local Creek Inflows

Several creeks drain large, urbanized watersheds to the northern portion of Suisun Marsh, including Green Valley Creek, Suisun Creek, Ledgewood Creek, Laurel Creek, Union Creek, and Denverton Creek. (Figure 8-1). For instance, Ledgewood Creek flows along the west edge of the City of Fairfield. The creeks convey seasonal freshwater to Suisun Marsh as well as urban runoff, which could be a source of biological oxygen demand (BOD) (Siegel et al. 2011).

#### Fairfield-Suisun Wastewater Treatment Plant (FSSD)

The FSSD advanced secondary Wastewater Treatment Plant is located in the northwest portion of the marsh and serves more than 130,000 residential, commercial, and industrial customers, and discharges approximately 13 mgd. Approximately 90% of the plant's effluent discharges into Boynton Slough. The remainder of the discharge is recycled for landscape irrigation. A smaller discharge point exists on Ledgewood Creek in case of high effluent flows or failure of the primary discharge point to Boynton Slough.

#### Precipitation

Suisun Marsh receives about 25 inches of annual precipitation in comparison to tidal exchange of 4–11 inches per week, and 3–8 inches per week measured at two intensively-monitored wetlands (Siegel et al. 2011). Precipitation to Suisun Marsh is of small hydrologic influence compared to tidal exchange.

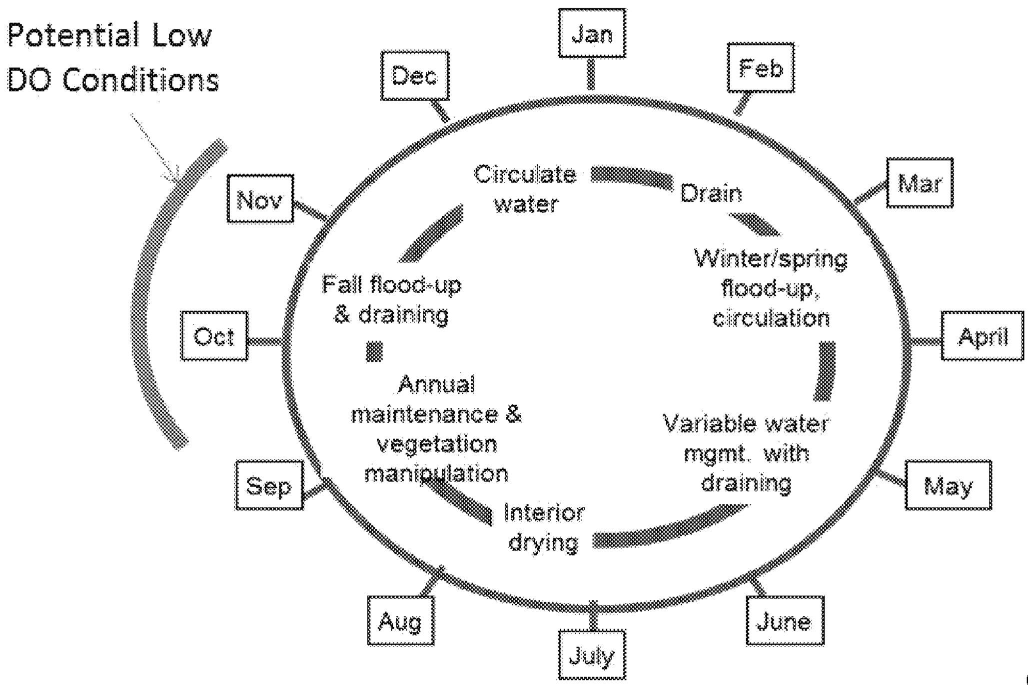
### *2.1.2 Role of Managed Wetlands*

Managed wetlands are diked and separated from tidal sloughs by levees, with water exchange controlled by gated culverts. The primary goal of seasonal wetland management in Suisun Marsh is to provide wintering habitat for waterfowl, with a secondary goal of salinity control.

The following are the primary tools used in managed wetlands to create a habitat mosaic desired by waterfowl (Figure 2-3):

- Water management:
  - Controlled flooding and circulation of water within the wetland to maintain the desired water levels, provide additional feeding habitat and flush salts and decaying plant material.
  - Seasonal draining and drying of the wetland to promote seed germination and plant growth.
- Burning, disking, mowing and other actions to manipulate and enhance wetland vegetation, which can contribute to an organic carbon buildup.

The general wetland management cycle includes a summer period, when wetlands are left to be relatively dry, although some level of ponding may be present year-round. During the summer, vegetation is mowed or disked and the vegetation debris left in situ. Water management usually begins in early October with the "fall flood-up," when managed wetlands (or ponds) are flooded with water from the adjacent sloughs and channels (DWR 2001). When managed wetlands are flooded, vegetation in them starts to decompose, which may result in the depletion of oxygen and the production of sulfides. During the fall flood-up, water that has remained ponded in the wetland over the summer is discharged, along with the vegetation debris. Because of the decomposition of organic matter in the ponded wetland, the ponded water and the water that has initially entered during the fall flood-up, may have very low DO concentrations, or be anoxic. When this potentially anoxic water is discharged to adjoining sloughs, it may lead to a dramatic decrease in DO concentrations especially in smaller sloughs. These low DO events prevail when temperatures are high, circulation rates are low, and there is a large amount of dead broad-leafed vegetation and other organic material (DFG 2010). Although this combination of factors often occurs in fall, it can also occur throughout the winter. The water management contains several flood and drain cycles, including the major cycle in the fall and several minor cycles during late winter/spring. Complete and partial drainage of the ponds begins after the waterfowl season ends in January.




*(Modified from DFG 2010)*

**Figure 2-3 Conceptual representation of the typical water management cycle at a managed wetland**

## 2.2. Beneficial Uses

Beneficial uses of water bodies help determine water quality objectives, which should be met in the water body. The beneficial uses for Suisun Marsh wetlands and the two major sloughs are shown in Table 2-1.

**Table 2-1**
**Existing beneficial uses of water bodies in the Suisun Marsh region**

| | Aquatic Life Uses | | | | | Wildlife Use | Recreational Uses | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EST | MIGR | RARE | SPWN | WARM | WILD | REC1 | REC2 | NAV | COMM |
| Suisun Marsh (wetland) | E | E | E | E | | E | E | E | | E |
| Suisun Slough | | | | E | E | E | E | E | E | E |
| Montezuma Slough | | | E | E | E | E | E | E | E | E |

E – existing beneficial uses

| | |
|---|---|
| EST | estuarine habitat |
| MIGR | fish migration |
| RARE | preservation of rare and endangered species |
| SPWN | fish spawning |
| WARM | warm freshwater habitat |
| WILD | wildlife habitat |
| REC1 | water contact recreation |
| REC2 | noncontact water recreation |
| NAV | navigation |
| COMM | commercial and sport fishing |

The goal of the DO TMDL is to restore and protect the most sensitive aquatic life beneficial uses (EST, MIGR, RARE, and SPWN). Since mercury concentrations in fish pose risks to human health, and are potentially hazardous to birds and mammals that consume fish, extending San Francisco Bay Mercury TMDL to Suisun Marsh aims to protect sport fishing (COMM), RARE, and WILD.

# 3. PROBLEM STATEMENT AND IMPAIRMENT ASSESSMENT

## 3.1. WATER QUALITY CONCERNS

Suisun Marsh sloughs have experienced frequent low DO events and fish kills since at least 1993, when black water and dead fish were first observed. (Schroeter and Moyle 2004). The University of California at Davis (UC Davis) has monitored fish abundance in the marsh on a monthly basis since 1979 but after a reported fish kill in the fall of 1999, initiated DO monitoring as well. Since then, several fish kills and low DO events have been observed, in the fall of 2001, 2003, 2004, and 2009 (Table 3-1).

**Table 3-1**
**Fish kills reported for sloughs within Suisun Marsh**

| Year | Description | Additional Information | Reference |
|---|---|---|---|
| Fall of 1999 | Fish kill | Following a local pond discharge | O'Rear and Moyle, 2010 |
| Fall of 2001 | No information | | Schroeter and Moyle, 2001 |
| Summer and fall of 2003 | No information | | Schroeter and Moyle, 2003 |
| October and November 2004 | Large fish kills or absence of native species that are intolerant of low DO | DO levels at the time of discovery were 2.8 mg/L for three sites, and a low of 2.3 mg/L was recorded for Goodyear Slough. They were likely lower. | Stover et al. 2004 |
| October 2009 | Anoxic conditions in Goodyear Slough killed several species of fish including splittail, striped bass, and threespine stickleback. | 1) Discharge of black, anoxic water from duck ponds into Goodyear Slough; 2) poor water circulation; 3) High inputs of organic materials from storms; and 4) High input of organic material at the end of the growing season | O'Rear and Moyle, 2010 |

The fish kills in 2004 and 2009 were the two largest and best-described events reported for Suisun Marsh. In October 2004, dead fish were seen in several sloughs, including Peytonia, Boynton, Goodyear, and Suisun Sloughs, and corresponded to low DO observed in these sloughs. The DO concentrations observed in different sloughs during the 2004 fish kill are shown in Figure 3-1 and Table 3-2. During that period, the measured DO were as low as 0.3 mg/L in Goodyear Slough and as low as 0.9 mg/L in Boynton Slough and Peytonia Slough. The reported DO levels may not directly represent the conditions that led to fish kills as they were measured after the event. Fish mortality was reported for different species, including relatively tolerant species, such as Sacramento splittail, Sacramento sucker, and carp.

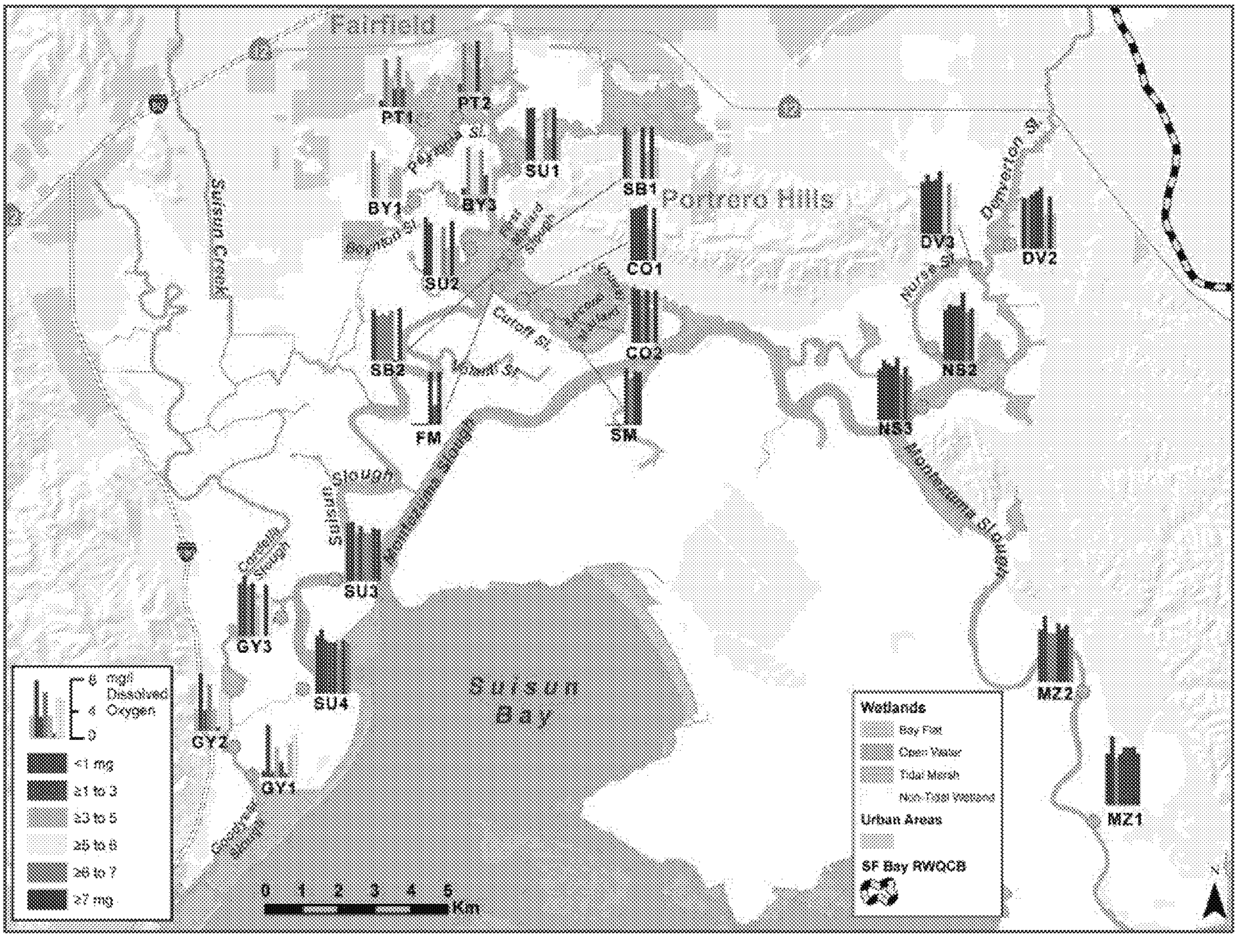
The 2009 low DO event resulted in mortality of several fish species in the upper Goodyear Slough, some of which are relatively tolerant of low DO conditions. The dead fish included bluegill, splittail, adult striped bass, threespine stickleback, and Mississippi silversides. The fish kills mostly occurred in dead-end sloughs adjacent to managed wetlands after discharge events.

**Table 3-2**
**Dissolved oxygen concentrations observed in Suisun Marsh Sloughs in fall 2004**

| Date | Slough | Site | DO (mg/L) | % Saturation |
|---|---|---|---|---|
| 10/12/2004 | Boynton Slough | BY1 | 5.6 | 59.8 |
| 10/12/2004 | Boynton Slough | BY3 | 0.9 | 9.3 |
| 10/12/2004 | Chadbourne Slough | CHAD | 4.9 | 62.8 |
| 10/14/2004 | Cutoff Slough | CO1 | 5.8 | 62.8 |
| 10/14/2004 | Cutoff Slough | CO2 | 5.9 | 65 |
| 10/13/2004 | Goodyear Slough | GY1 | 0.3 | 3.2 |
| 10/13/2004 | Goodyear Slough | GY2 | 3.2 | 36.7 |
| 10/13/2004 | Goodyear Slough | GY3 | 7 | 77.4 |
| 10/12/2004 | Peytonia Slough | PT1 | 0.9 | 9.7 |
| 10/12/2004 | Peytonia Slough | PT2 | 1.1 | 10.8 |
| 10/14/2004 | First Mallard | SB1 | 6.2 | 68 |
| 10/14/2004 | First Mallard | SB2 | 6.1 | 66.7 |
| 10/12/2004 | Sheldrake Slough | SHLD | 7.6 | 84.9 |
| 10/12/2004 | Suisun Slough | SU1 | 7.6 | 80 |
| 10/12/2004 | Suisun Slough | SU2 | 8.2 | 87.2 |
| 10/13/2004 | Suisun Slough | SU3 | 7.8 | 86.6 |
| 10/13/2004 | Suisun Slough | SU4 | 7.1 | 78.2 |

Fish mortality as a result of low DO does not appear to have occurred uniformly or in all regions or sloughs within the marsh. Different regions provide distinct habitats and hydrology, and water quality in individual sloughs is a consequence of different natural and anthropogenic drivers. Low DO appears to be more of a problem in the back-end sloughs of the western part of the marsh, which have limited tidal circulation, and also have a relatively high density of duck clubs (Figure 3-1). In these smaller sloughs around the margins of Suisun Marsh, fall floodup can trap the low quality waters at the headward end of the sloughs, which reduces already-limited tidal exchange and leads to reduced DO levels in these waters (Siegel et al., 2011).

In comparison, sloughs in the eastern portion (i.e., Denverton, Nurse, and Montezuma sloughs) and lower portion of Suisun Slough (Figure 3-1), have better water quality. This is likely to result from better natural circulation, higher flows, and the relatively lower volume of managed wetland discharges.



Bars represent DO concentrations measured in grab samples in October from 2004 through 2011. Bar hights and colors indicate DO values.

**Figure 3-1 Dissolved oxygen concentrations in Suisun Marsh sloughs in October 2004-2011**

## 3.2. CAUSES OF LOW DO IN SUISUN MARSH

Low DO concentrations in the sloughs are likely to result from decomposition of organic material originating from terrestrial inputs and *in situ* production. The sloughs are naturally highly productive and accumulate large amounts of aquatic plant material and detritus, which is essential for a healthy estuarine ecosystem. Although the sloughs receive inputs from creeks that drain agricultural and urbanized areas, the operation of managed wetlands was shown to have a strong effect on the DO concentrations when hypoxic water from managed ponds was discharged into sloughs during fall and spring draining events. DO concentrations were notably higher in April, possibly due to higher wind speeds that promote mixing and re-aeration that time of the year (Siegel et al. 2011).

A conceptual model of the causes and effects of low DO in small sloughs is presented in Figure 3-2 (based on a schematic previously developed by Siegel et al. 2011). The diagram illustrates the interaction of management actions, external sources, internal processes and specific outcomes such as low DO in waters and resulting fish kills.

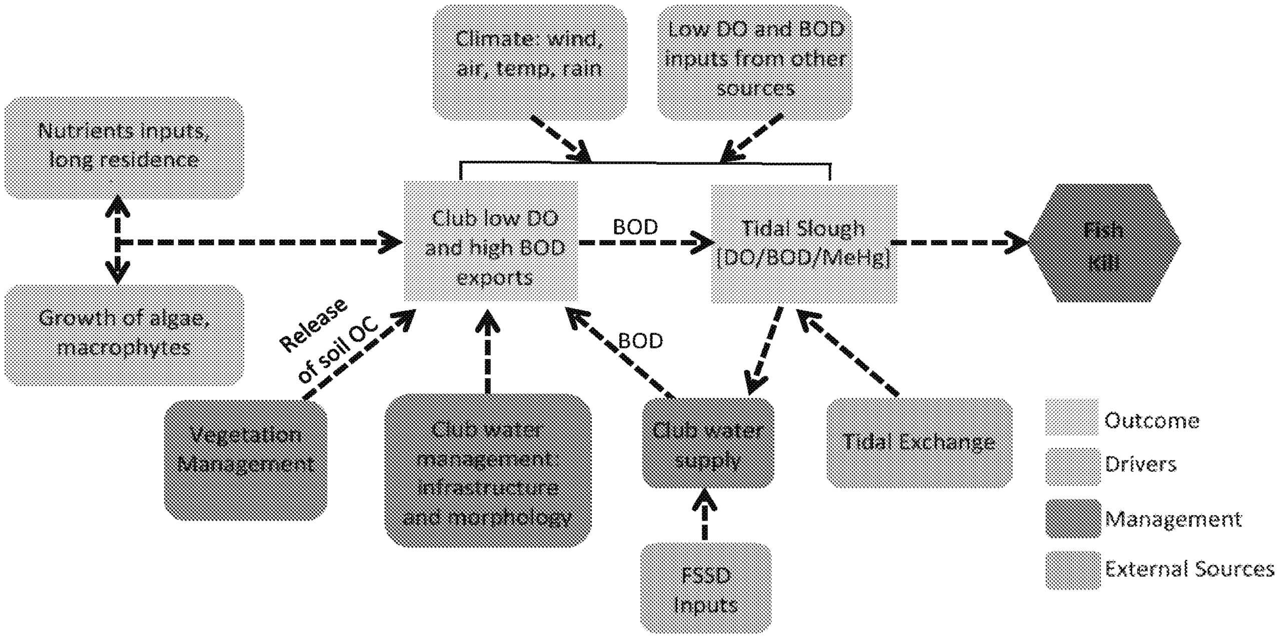



**Figure 3-2 Causes of low DO in small tidal sloughs in Suisun Marsh**

Aerobic bacteria need oxygen to break down organic materials present in a water body: the amount of dissolved oxygen they need is called biochemical oxygen demand (BOD). When BOD is high, DO is low because most oxygen is being used by bacteria in the decomposition process. Two types of materials that contribute to high oxygen demand, measured as BOD, are naturally present in large quantities in Suisun Marsh: organic carbon and nutrients. Potential increases in BOD result from discharges from managed wetlands and to a lesser extent storm water runoff from urbanized, agricultural, and grazed open areas and nutrient-enriched wastewater discharge from FSSD. In addition, high internal production of phytoplankton within sloughs and wetlands, wetland vegetation and decomposition of soil organic carbon within wetlands adds a considerable amount of organic carbon to the sloughs and results in naturally elevated BOD that may deplete oxygen in the water. Studies show that estuaries receiving drainage from natural wetlands and marshes may exhibit a wide range of DO, ranging from below 2 mg/L to more than 8 mg/L, while still maintaining healthy biological communities (FDEP 2013).

The western portions of Suisun Marsh are of the most concern due to a higher number of managed wetlands and limited mixing in small dead-end sloughs. The eastern parts of Suisun Marsh receive less discharge from the managed wetlands and have larger sloughs. Most of the severe low DO events and fish kills have been recorded in small sloughs in the west of Suisun Marsh. The lower Suisun Slough and Montezuma Slough are characterized by larger size, greater tidal mixing, and higher DO. A more detailed discussion of DO concentrations in sloughs is presented in Appendix B.

## 3.3. DO Concentrations within Managed Wetlands

DO monitoring within managed wetlands helps characterize the water quality of their discharges during drain events. In the study by Siegel et al. (2011), intensive DO monitoring was conducted for two consecutive years 2007-2008 at two managed wetlands (Wetland 123 and 112). DO was monitored at stations along the perimeter and in the interior of each managed wetland. During the fall drain events, DO concentrations at the perimeter monitoring stations were 1.5 mg/L before drainage, and dropped to near 0 mg/L, and remained at 0 mg/L for several days during drainage. DO concentrations at the interior monitoring stations mostly remained at low concentrations throughout the fall period. The managed wetlands were also drained 2–3 times during spring. During the spring drawdown events DO concentrations in the wetlands decreased to near 0 mg/L; however, they recovered in a relatively short time (Bachand et al. 2010).

## 3.4. Seasonal and Critically Low DO Conditions

Dissolved oxygen concentrations in western Suisun Marsh vary seasonally; however, many of the sloughs monitored have DO levels above 5 mg/L, most of the time. DO sags tend to occur in late summer and fall (mid-September through mid-November) and are linked to the water management cycle at the managed wetlands. During the managed wetland discharge season, DO in the back-end sloughs in wesatern Marsh is generally depressed (i.e., below 5 mg/L). Low DO concentrations following managed wetland discharge events can last from several days to up to a week. Figure 3-3 shows the declines in DO measured in Peytonia Slough as a result of discharge from the managed wetlands on September 26 and November 4, 2013. In September, immediately after discharge, DO dropped to below 1 mg/L for a few hours per day, however it recovered within one tidal cycle once the tide stage increased and more water was available for mixing. Although recently observed DO in sloughs receiving discharges from managed wetlands was periodically at levels that could cause fish mortality (< 2 mg/L), it did not appear to result in fish kills. Reduced frequency and loads of DO to the smaller sloughs following the changes in water management at managed wetlands might have contributed to less severe impacts on fish.

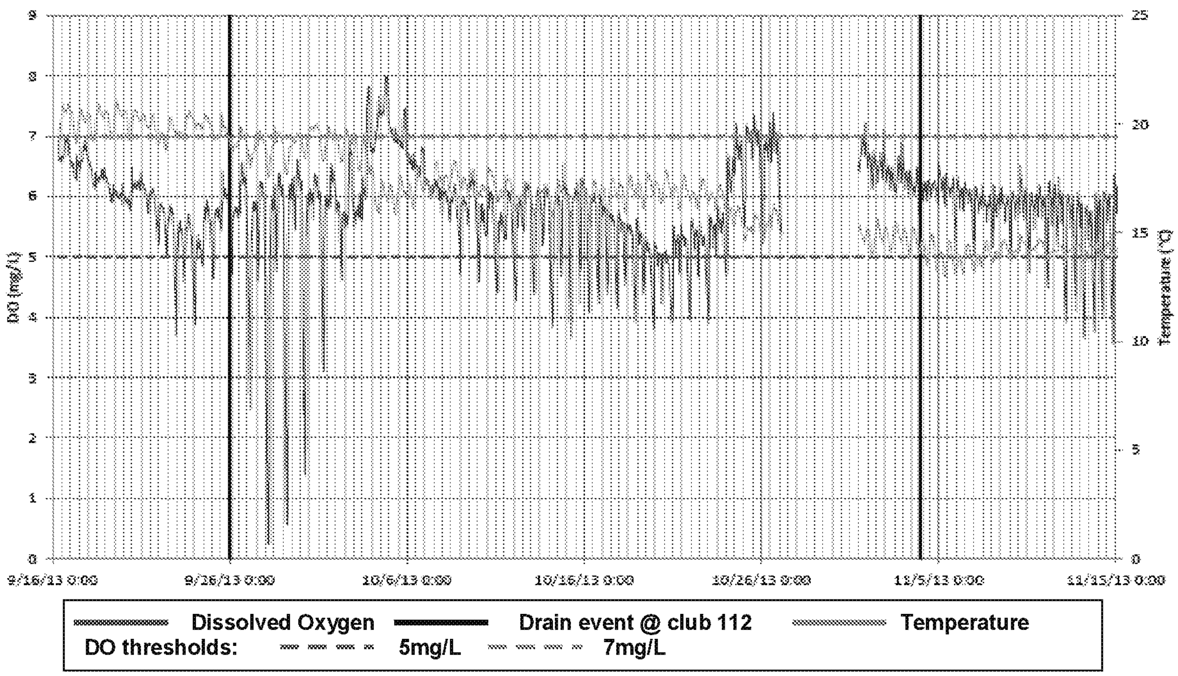



**Figure 3-3 Peytonia Slough DO and temperature trends during fall discharge**



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Fall drain events appear to be the critical times when low DO concentrations in the managed wetland discharges can cause adverse impacts on fish and other aquatic organisms. The fall drain events usually result in longer lasting and much lower DO concentrations than the spring events. During the fall drain events the sloughs in the west are characterized by relatively low net flow and limited mixing. In spring, drain events also contribute to DO declines, however, due to higher net flow in the sloughs in the downstream direction and possibly greater mixing as a result of higher wind speeds, DO depressions in the sloughs are less severe than in the fall season.

Continuous monitoring of DO in Goodyear Slough has been conducted since August 2012 (Figure 3-4, Figure 3-5). In the fall of 2012, prior to discharge from the managed wetlands, DO concentrations in Goodyear Slough were around 7 mg/L between 08/12–10/12, and started to decrease from the middle of October, which coincided with the beginning of the drain period from the duck clubs (Figure 3-4). DO concentrations stayed low for the period of 10/12–12/12, and then started to increase from late December and stayed at around 7 mg/L from 12/12 until 01/13. During the low DO period (10/12–12/12), DO concentrations in Goodyear Slough reached as low as 1 mg/L.

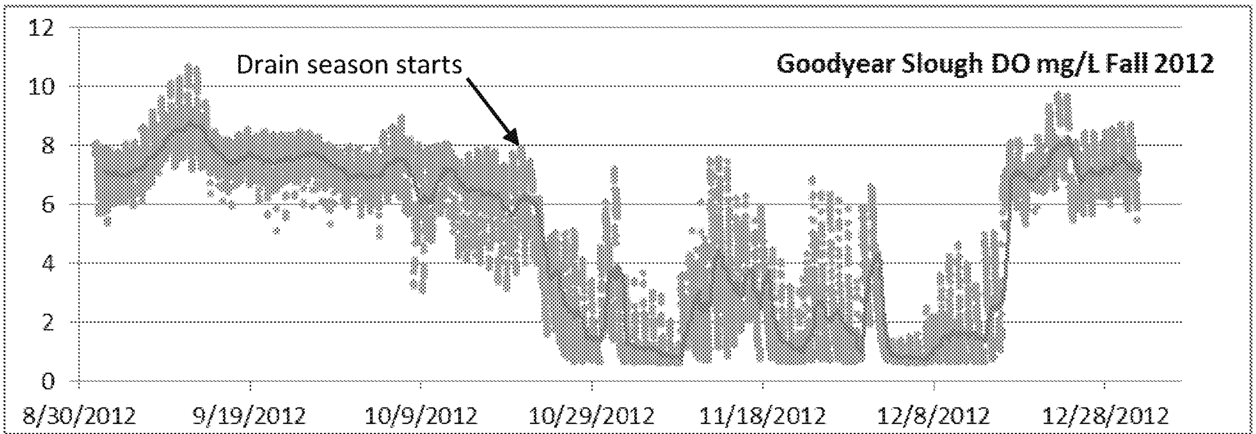



**Figure 3-4 DO concentrations in Goodyear Slough during 2012 fall drain event**

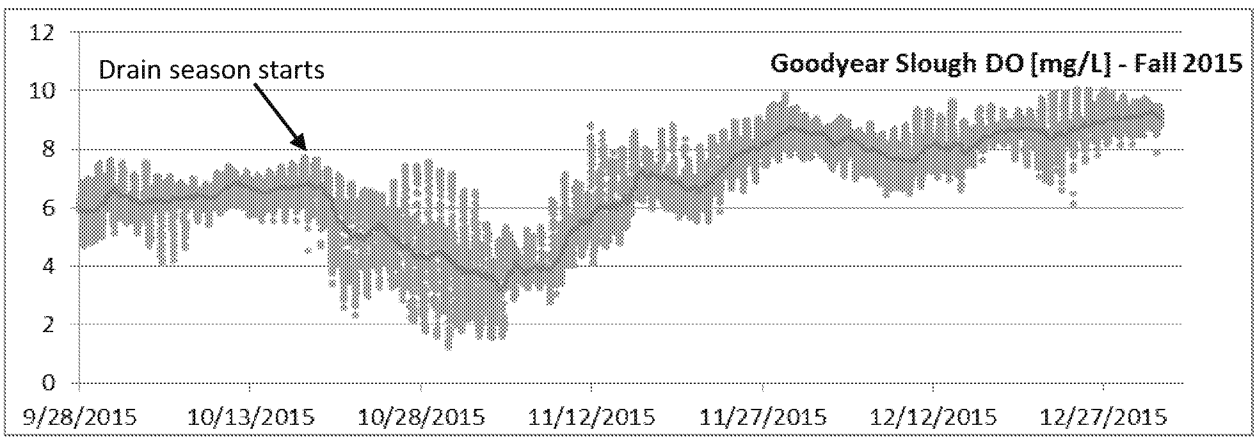


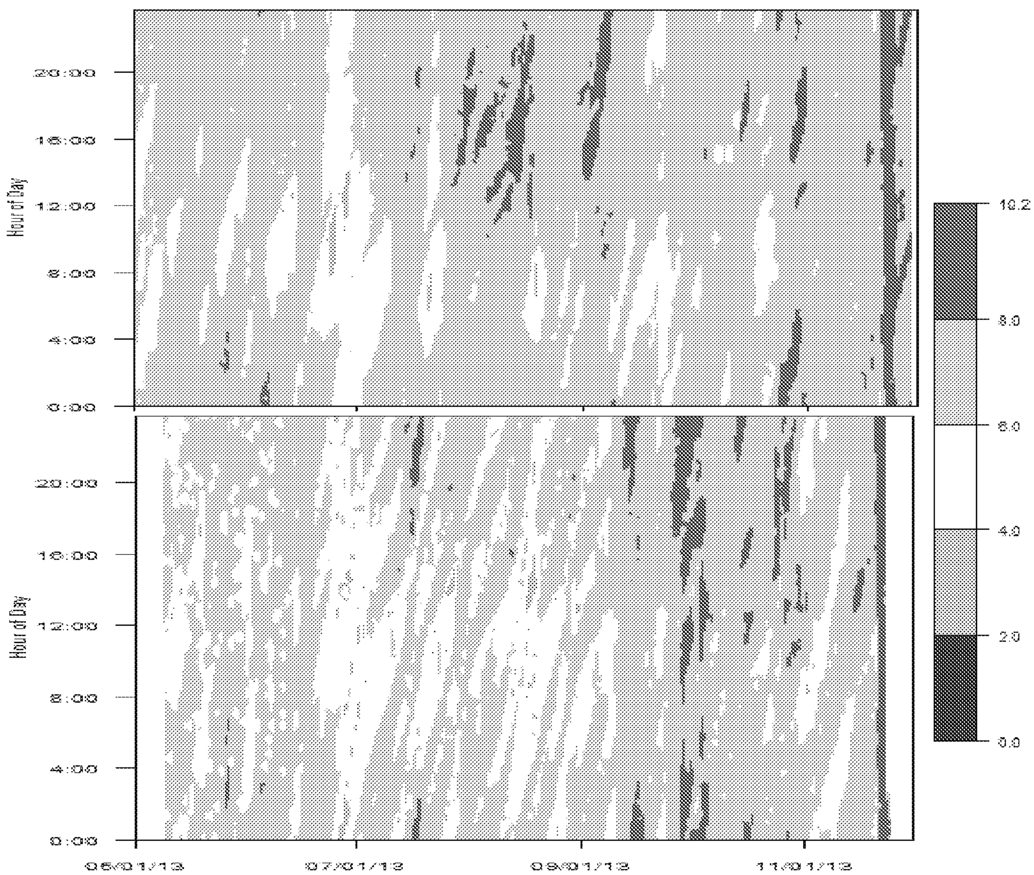

**Figure 3-5 DO concentrations in Goodyear Slough during 2015 fall drain event**



ED_002551_00001479-00024

Recent data (2013-15) suggest that DO conditions in the sloughs have improved compared to earlier years. Trial implementation of best management practices (BMPs) at managed wetlands from 2013 onward appears to be successful at reducing impacts of their discharges on slough water quality (Figure 3-4, Figure 3-5). The employed BMPs included staggering the discharges from multiple managed wetlands, diverting discharge water to larger sloughs, and mowing vegetation early to allow for further decomposition before fall flood up. Managed wetlands that were near Peytonia and Boynton Sloughs also used a combination of water management and selective spraying to promote the growth of wetland grasses instead of broad leaf plants, which helps reduce the volume of vegetative matter and BOD load to the sloughs. In general, the overall average DO levels during the fall discharge period were higher in 2015 than in 2012 and 2007-08, and the DO depressions were much shorter.

Due to the wider slough channels, more extensive tidal mixing and lower density of managed wetlands, sloughs in the eastern part of the marsh, and especially larger sloughs such as Denverton or Montezuma Slough, maintain better DO conditions throughout the year. DO patterns in Denverton Slough also resemble those in First Mallard Slough, which is considered to be minimally impacted and representative of more natural DO conditions (Figure 3-6).




Note: DO minima (yellow/orange) in the graph often coincide with low tides.

**Figure 3-6 Comparison of DO patterns in First Mallard (top) and Denverton Slough (bottom)**

### 3.5. CONTRIBUTION OF NUTRIENTS AND NUTRIENT IMPAIRMENT ASSESSMENT

The Water Board is in the process of identifying indicators of nutrient enrichment for San Francisco Bay. Here, we considered a subset of these indicators and the data available in the marsh to evaluate, on a preliminary basis, whether or not the Suisun Marsh sloughs are impaired by nutrients. These include: pelagic and benthic chlorophyll *a* concentrations, DO concentrations, and submerged aquatic vegetation/macroalgal cover. (Parker et al. 2015). We conclude that nutrients are not the main cause of the low DO observed in the marsh sloughs and that no clearly defined impairment exists. For more information about the presence and distribution of organic carbon and BOD see Section 6 of this report.

Although excessive nutrient enrichment in wetlands is considered to be one of the primary stressors adversely affecting ecosystem functions and causing undesirable shifts in composition of plants and aquatic organisms (USEPA 2008), the indicators to distinguish nutrient impairment resulting from anthropogenic stressors versus natural conditions are difficult to quantify. Often, the interpretation of these indicators requires extensive data collected from both targeted and reference (unimpacted) wetlands, which is difficult in the complex, and constantly changing ecosystem of Suisun Marsh. Unless in excess quantities or under physical conditions conducive to increased excessive algae production, nutrients themselves usually do not adversely affect beneficial uses and water quality.

Tidal wetlands are naturally rich in nutrients (eutrophic) compared to open water areas, and have the ability to assimilate nutrient inputs, mitigating anthropogenic nutrient loads via uptake and assimilation by phytoplankton and emergent vegetation. (e.g., Fisher and Acreman 2004, Vymazal 2007). However, increasing nutrient loads from anthropogenic sources can result in severe eutrophic conditions leading to decline in water quality (Bricker et al. 2007, Chapter 8). High nutrient concentrations (eutrophic conditions) may cause undesirable biological responses such as excessive benthic algal biomass, high chlorophyll *a*, low DO, macrophyte cover, and low water clarity. use of constructed wetlands is common to improve water quality and further reduce nutrient loads downstream of industrial and municipal wastewater discharges (e.g., Fisher and Acreman 2004, Vymazal 2007).

Nutrients, defined here as different chemical forms of nitrogen (nitrate, nitrite, ammonia) and phosphorus (PO4) enter Suisun Marsh through the tributaries draining agricultural and urban areas, from the Delta, through atmospheric deposition, and via discharge from the FSSD wastewater treatment plant. Elevated nutrient concentrations can potentially result in excess growth of phytoplankton and macrophytes and the subsequent decay of these materials may result in lowering of DO and increasing turbidity in wetlands and sloughs, conditions that could harm the health of aquatic organisms including fish. A conceptual representation of the cause-and-effect relationships for nutrients in Suisun Marsh is presented in Figure 3-7 (Tetra Tech 2013a, Appendix B).

Parker et al. (2015) evaluated all available data and examined the common nutrient enrichment indicators to assess the potential for nutrient impairment in Suisun Marsh sloughs and concluded that nutrient loading does not appear to be a major driver of the impaired ecosystem health via excessive phytoplankton growth or eutrophic shifts in dissolved oxygen. Seasonal and spatial trends and nutrient-related indicators appear to be within the range likely to occur naturally in the marsh environment. Concentrations of chlorophyll *a*, which is evaluated as an indicator of overproduction of algae, fluctuate seasonally and across different sloughs but are not high in Suisun Marsh. Mean chlorophyll *a* concentrations in western sloughs varied between summer lows of 6.0 µg/L and highest values in winter reaching 13.8 µg/L. Winter chlorophyll *a* showed large variability with one sample of nearly 46 µg/L; removing this one outlier observation resulted in mean winter chlorophyll *a* of 8.7 µg/L. These levels are consistent with average winter chlorophyll *a* (mean: 7.9 and 6.2 µg/L) measured at First and Second Mallard Sloughs, which are fully tidal and are minimally impacted by anthropogenic activities compared to other areas of the marsh. In addition, western sloughs, where nutrient concentrations are highest, do not always support the highest chlorophyll *a* concentrations (Parker et al. 2015). Accordingly, although low DO is frequently detected in small back-end sloughs, and fish kills had occurred in Suisun Marsh in the past, these adverse impacts do not seem to be directly related to excessive amount of nutrients in the marsh.

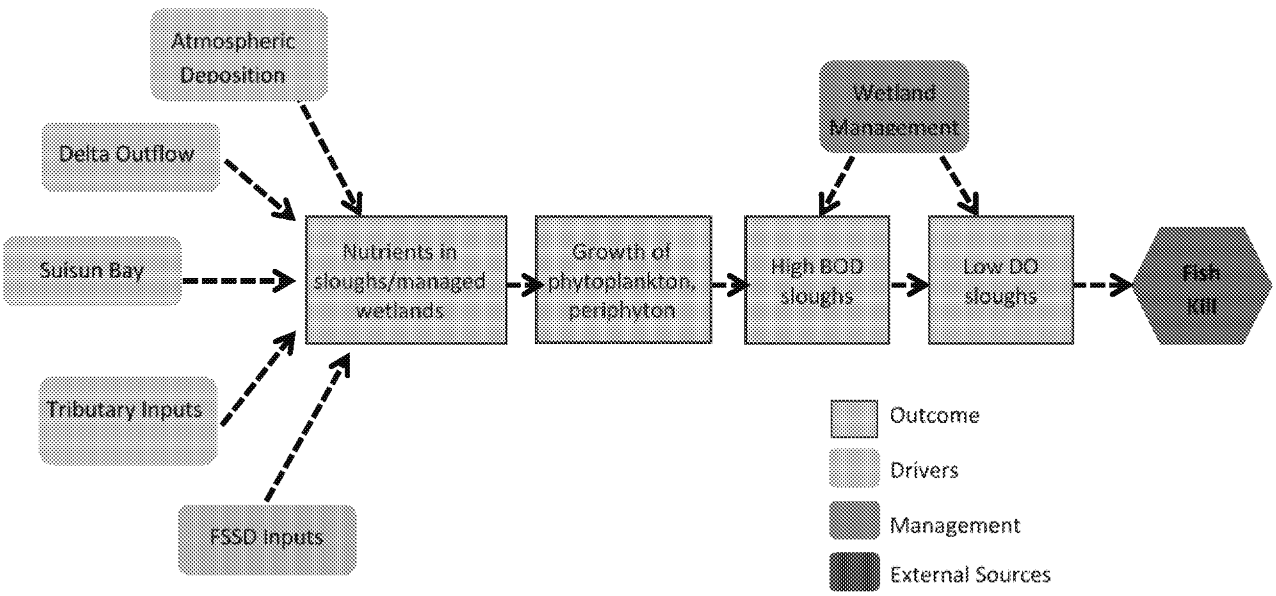



**Figure 3-7 Nutrient conceptual model (cause-effect relationship) in Suisun Marsh**

This assessment is based on limited data, however, it is also consistent with anecdotal information that Suisun Marsh sloughs, which support high biological productivity, can sustain phytoplankton blooms, which could inherently become a source of high BOD even without anthropogenic drivers.

## 3.6. MERCURY EFFECTS AND IMPAIRMENT ASSESSMENT

Mercury is highly toxic and can cause a number of adverse health effects in humans and wildlife. The concerns about bioaccumulation of mercury in fish, wildlife, and people that drove adoption of the San Francisco Bay Mercury TMDL (Bay Mercury TMDL) in

2006 justify extending the TMDL to Suisun Marsh. The historical and present sources of mercury to Suisun Marsh are similar, if not identical, to those in the Bay, because mercury from historic mining in the Sierras and other sources washes through the marsh on its way to the Bay. Mercury is converted to the more toxic methylmercury (methylation) principally by bacteria in sediments of aquatic ecosystems, especially near the boundary layer between oxygenated and non-oxygenated conditions. Methylmercury reaches higher concentrations with each step up the food chain – from water, to phytoplankton, to filter feeders, to small fish, to sport fish and humans, or to fish eating wildlife – in a process known as biomagnification (Figure 3-8).

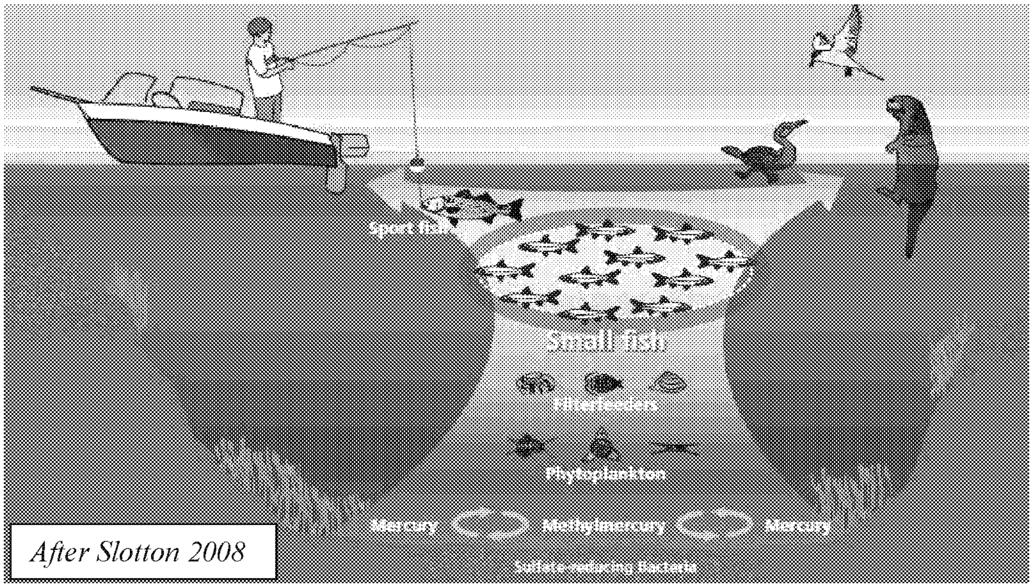



**Figure 3-8 Mercury movement in the food web**

The estuary has elevated mercury (Hg) concentrations in fish, sediment, and water, as compared to other North American estuaries, due to the history of Hg mining in the Coast Range mountains and the use of Hg for gold extraction in the Sierra Nevada mountains in the 19th century (Alpers et al. 2005, Heim et al. 2003, Wiener et al. 2003, Heim et al. 2008, Davis et al. 2008). Sulfate- and iron-reducing bacteria in anaerobic environments convert Hg to methylmercury (MeHg) (e.g., Gilmour et al. 1992, Yu et al. 2012).

Wetlands provide opportunities for MeHg production, or methylation, because of their wet/dry cycling, potential for elevated water temperatures, sources of labile carbon, and low redox conditions that enable sulfate and iron reducing bacteria to flourish. (St. Louis et al. 1994; Hurley et al. 1995; Rudd 1995; Gilmour et al. 1992; Yu et al. 2012).

Suisun Marsh is therefore an area of concern, because of the extensive presence of wetlands, the sources of inorganic mercury from water exchange with the Bay and Delta, and the occurrence of organic rich sediments and anoxic conditions that favor methylation. In a literature review on mercury in tidal wetlands (including managed wetlands in Suisun Marsh), it was found that these wetlands could be a significant source of methylmercury to surrounding waters (Tetra Tech 2013b).

Fish in Suisun Marsh have Hg concentrations that exceed the levels of concern for human health and wildlife. Hg concentrations in Mississippi silversides, a small fish approximately 3 inches long, were measured in Suisun Marsh in 2005-2010. All concentrations observed in silversides were consistently above 0.03 mg/kg (30 ng/g), the water quality objective for prey fish established to protect wildlife by the Bay Mercury TMDL (Figure 3-9).

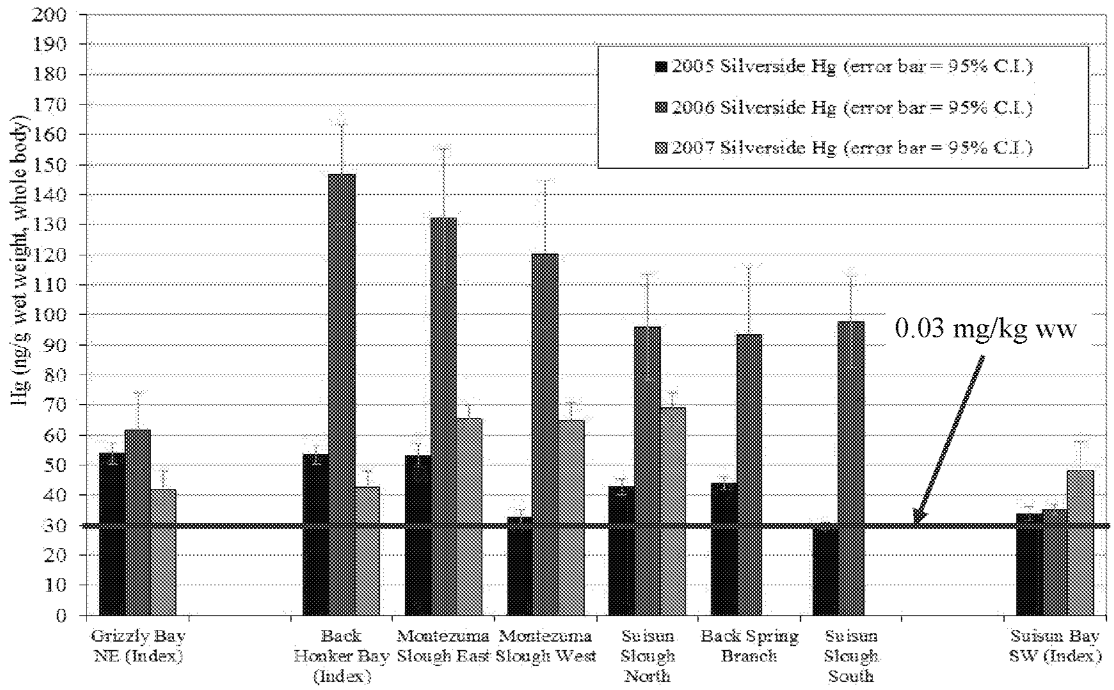



**Figure 3-9 Summary of mercury in Silversides in Suisun Bay and Suisun Marsh Sloughs**
(Data: Darell Slotton, UC Davis, *pers. comm.*)

Concentrations of Hg measured in silversides vary significantly across seasons and locations in the Bay. The highest concentrations are usually detected in fish caught in the South Bay (mean concentrations: ~80-260 ng/g; Greenfield et al. 2009). Although the concentrations in silversides caught in Suisun Marsh sloughs (Figure 3-9) are still above the objective, they are lower than those in the South Bay and generally comparable to the levels of Hg found in fish from managed ponds and sloughs in the Napa-Sonoma marshes (Grenier et al. 2010) and in the north Bay. The average concentrations in the 40-70 ng/g range were considered as indicative of the low-end Hg concentrations in the Napa-Sonoma region. The 1.5 to 2 fold differences in concentrations between the lowest and highest seasonal levels or differences between years observed in Suisun Marsh are also typical of the variation observed in the Napa-Sonoma marshes.

Concentrations of Hg in common sport fish (bass and white catfish) caught in Suisun Marsh sloughs in 2013 (Figure 3-10) confirm a wide-spread contamination of fish with Hg, with levels in all 10 fish exceeding the human health target of 0.2 mg/kg wet weight established for the Bay Mercury TMDL (SFBRWQCB 2006). Hg concentrations in the water column are approximately two orders of magnitude below the applicable acute water quality objective of 2.1 µg/L (Figure 3-11) which is expected because chronic exposure to elevated concentrations in the food web is more of a concern than exposure to high levels of Hg in the water column. For a more detailed discussion of the available mercury data, see Suisun Marsh Conceptual Model/Impairment Assessment Report by Tetra Tech (2013a).

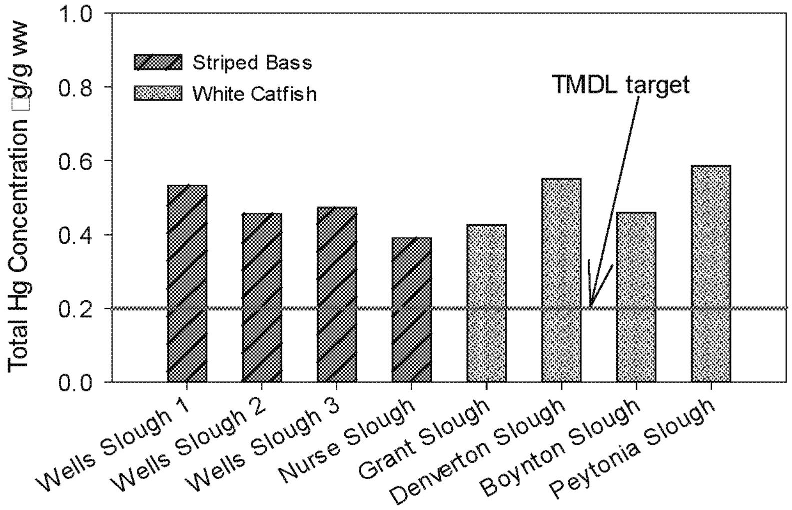



**Figure 3-10 Mercury concentrations in sport fish caught in Suisun Marsh sloughs**

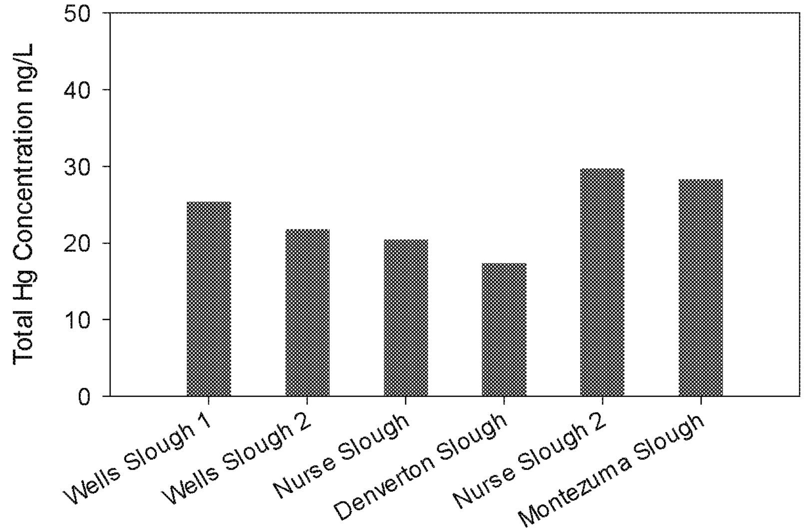



**Figure 3-11 Total mercury concentrations in water column in Suisun Marsh sloughs**

# 4. NUMERIC TARGETS: REFINEMENT OF DISSOLVED OXYGEN OBJECTIVES FOR SUISUN MARSH

## 4.1. RATIONALE FOR REFINING WATER QUALITY OBJECTIVES FOR SUISUN MARSH

Dissolved oxygen objectives, unlike traditional objectives for toxic substances, are often region- or waterbody-specific because the DO regime is dependent on temperature, hydrologic conditions, and natural biological processes, all of which vary geographically.

The San Francisco Bay Basin Plan identifies DO objectives for waters that are upstream of the Carquinez Bridge as being a minimum of 7.0 mg/l. It also includes a requirement that the median DO concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation. These water quality objectives were adopted in the 1975 Basin Plan and are generally being attained in most of the Bay's subtidal waters. The Basin Plan does not clearly address the applicability of these objectives to Marsh tidal sloughs and managed ponds as in Suisun Marsh where there is some evidence they may not be attainable.

It is also unclear whether the existing Basin Plan's DO objectives are appropriate in shallow, dynamic, biologically productive habitats like Suisun Marsh. Dissolved oxygen concentrations in shallow water habitats, such as tidal wetlands and slough networks, vary much more compared to the main water mass of San Francisco Bay and frequently exhibit concentrations less than 5.0 mg/L and less than 7.0 mg/L (Tetra Tech 2013a). The 1975 objectives do not take into account that DO concentrations in marshes and wetlands might be low due to naturally-occurring organic enrichment or due to patterns of tidal fluctuations in shallow water habitats. In addition, the objectives for the Bay, while protective of fish and other sensitive biota in San Francisco Bay did not systematically consider any species-specific requirements. Furthermore, the 1975 objectives were not derived with consideration of continuous sampling, and do not provide latitude with respect to allowable exceedances, on a temporal or spatial scale. Specifically, the objectives do not include weekly or monthly average limits representative of chronic exposures and effects of DO stress. They are expressed as instantaneous limits, which presents a challenge when interpreting data recorded continuously (measured at 15 minute intervals), which show natural daily and seasonal fluctuations. The natural pattern and the range of diel DO concentrations is affected by the level of photosynthesis and respiration. It fluctuates with temperature, salinity and pressure changes and in Suisun Marsh is further augmented by the tidal cycle. Figure 4-1 illustrates daily change in DO measured in Goodyear Slough with a YSI sonde under no discharge from duck clubs, showing DO concentrations ranging from 4 mg/L to over 8 mg/L on daily basis.

Therefore, refinement of the DO objectives was necessary to establish appropriate and attainable numeric targets for the TMDL that protect biological communities in Suisun Marsh, reflect the natural organic enrichment in the marsh, and consider the currently available scientific information and monitoring tools. Given the complexity of the task, we convened an Expert Panel of scientific and policy experts to provide advice on the development of refined objectives. The Panel included Peter Moyle (UC Davis, CA), Paul Stacey (Great Bay National Estuarine Research Reserve, NH) and Peter Tango (USGS Chesapeake Bay, MD). The proposed objectives reflect the best available science and the Expert Panel recommendations regarding fish and invertebrate responses to stress from the low DO, the level of protection needed for sensitive and endangered species, and the application of a U.S. EPA approved approach to provide scientifically-defensible DO objectives for Suisun Marsh.

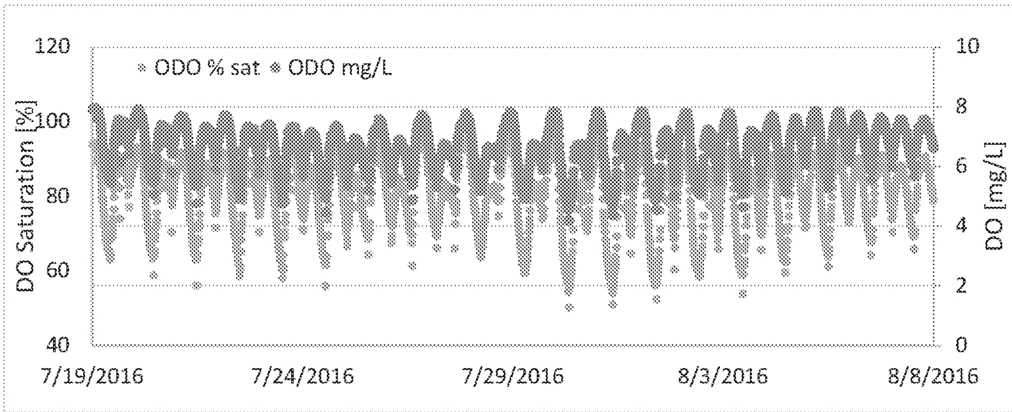



**Figure 4-1 Diurnal DO fluctuations in Goodyear Slough**

## 4.2. Derivation of DO Objectives

### *4.2.1 Rationale for Choosing a Method to Derive the Objectives*

In the refinement of the DO objectives for Suisun Marsh we followed the approach recommended by U.S. EPA for the Virginian Province (USEPA 2000), This approach supports the derivation of region-specific DO criteria tailored to the species, habitats and DO exposure regimes of varying estuarine, coastal and marine waters. The ability to select aquatic organisms and their life stage allows the criteria to be adapted to protect species relevant to Suisun Marsh. This method provides a framework for the establishment of DO thresholds under persistent long-term exposure and episodic short-term exposure, and considers three aspects of biological health: 1) survival of juveniles and adults, 2) growth of juveniles, and 3) larval recruitment. This approach combines current understanding of biological responses to hypoxic stressors in an estuarine ecosystem, and establishes a basis for the development of site-specific DO requirements.

Since organism-level laboratory data forms the basis of the criteria calculations, the U.S. EPA approach does not address directly some of the physiological effects or behavioral responses sometimes observed in low DO waters. There is a large body of research on indirect or sublethal effects of hypoxia resulting from, for example, contracting of habitats, increased predation, or altered trophic interactions (e.g., Eby et al. 2005, Vaquer-Sunyer and Duarte 2008, Seitz et al. 2009), and also summarized in U.S. EPA (2000). We considered these ecological interactions while developing the objectives and in discussions with the Expert Panel. Many aspects of hypoxia, relevant to Suisun Marsh, have been already reviewed by McKee et al. (2011), as part of the larger effort to develop nutrient water quality objectives for the San Francisco Bay estuary of which Suisun Marsh is an integral part, and in support of setting the DO objectives for California estuaries (Sutula et al. 2012). The latter study discusses assumptions, uncertainties and an application of the Virginian Province approach to derive the DO criteria for estuaries in California. Some effects such as local acclimation and adaptation to low DO conditions (Decker et al. 2003) could result in a population that is less sensitive than predicted from laboratory studies, whereas increased predation or contracting habitats could result in under-predictions. Therefore, we concluded that the uncertainties in this method were not likely to affect the level of protection set by the criteria.

Quantifying impacts of sublethal effects on fish populations has been challenging because of the large amount of interannual variability, multiple stresses that usually exist in aquatic systems, and high recruitment variability associated with coastal species. In derivation of the criteria for the Virginian Province, the U.S. EPA, however, recognized that the established criteria were protective of the above effects because most of the observed responses occurred at levels below 2.3 mg/L. The conservative assumptions used in the modeling, together with the exposure thresholds derived from experiments under the continuous low DO conditions, make the resulting criteria protective of most indirect adverse effects.

The U.S. EPA approach represents a synthesis of knowledge regarding biological responses to hypoxic stressors in aquatic ecosystems, is consistent with the guidelines for setting the water quality criteria for other pollutants (Stephen et al. 1985), and as such provides the best available tool for setting the site-specific objectives for Suisun Marsh. Therefore, although we evaluated a variety of approaches to set site-specific dissolved oxygen objectives in Suisun Marsh, we concluded that the U.S. EPA (2000) approach relied on the best-available scientific method that incorporated past and current scientific knowledge, and also met the regulatory backing required for criteria setting. The Expert Panel also endorsed this approach. See Tetra Tech (2017) for a detailed description of this methodology and how it was applied to derive the objectives for Suisun Marsh.

### 4.2.2 Summary of USEPA Virginian Province Approach

The Virginian Province approach (USEPA 2000) recommends a methodology for deriving DO levels necessary to protect coastal and estuarine organisms. It was originally developed for the Cape Cod Region, and was subsequently used to derive site-specific criteria for other large estuarine systems (e.g., Chesapeake Bay or state-wide objectives in Florida). The criteria are derived from laboratory data for organisms that occur in a particular area of interest, following the general approach used to develop criteria for toxic compounds (Stephen et al. 1985). Acute effects describing lethality to 50% of test organisms ($LC_{50}$) and chronic effects describing the most sensitive endpoint (growth in the case of DO) are obtained from the laboratory data. Toxicity data are ranked according to genus mean acute (or chronic) values (GMAV or GMCV) from most to least sensitive to DO. The four most sensitive GMAVs for acute criteria or GMCVs for chronic criteria, and the number of genera for which acceptable data are available, are then used to determine the Final Acute Value (FAV) or Final Chronic Value (FCV). This approach considers the response to both continuous and cyclic exposures to low DO